Investigation into Locking Point of Asphalt Mixtures Utilizing Superpave and Marshall Compactors

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Abstract: Locking point is an important concept in selecting a proper aggregate gradation in the asphalt mixture design. The locking point can be defined as the moment during asphalt mixture compaction at which an aggregate structure becomes stable. Beyond this point, further compaction does not contribute much to the increase in mixture density and can even damage aggregate particles. This study employed two compaction methods, a Superpave Gyratory Compactor and a Marshall Compactor, to investigate the locking points of different asphalt mixtures. For the Marshall compaction method, an accelerometer was attached to the Marshall Hammer to record the response of the asphalt mixtures. For the Superpave gyratory compaction, changes in the height and density of the compacted samples were utilized to determine locking points. A total of ten mixtures was designed and evaluated. All the mixtures were prepared with the same asphalt binder PG 64-22 and aggregates. The aggregates were prescreened by different sieves to control variability in gradation. The results of this study show that it is feasible to determine the locking point for most of the mixtures with an accelerometer. The one exception was the largest aggregate, which experienced particle breakage during compaction. The locking point was found to be dependent on the full range of aggregate sizes of a mixture. Stone mastic asphalt (SMA) mixtures with similar gradation in fine particles showed less variability in locking point. Dense-graded mixtures with smaller maximum aggregate size exhibited lower locking points. These results can be attributed to their higher asphalt content, which served as a lubricant. The 101.6-mm (4-in.) Marshall mold was not adequate for determining the locking point for the mixtures with particles larger than 25.4 mm (1 in.). **DOI: 10.1061/(ASCE)MT.1943-5533.0002839.** *© 2019 American Society of Civil Engineers.*

Author keywords: Locking point; Accelerometer; Compactibility; Superpave Gyratory Compactor; Marshall Hammer.

Introduction

Compaction is critical for asphalt mixture design, construction, and service. In asphalt mix design, compaction of asphalt mixture specimens is used to determine the optimum properties of the mix. During construction, compaction is applied to achieve target density requirements. Over the service life, asphalt pavement is constantly subjected to compaction by tires of vehicles (Asphalt Institute 2007).

Asphalt mixtures have been used in pavement construction since the beginning of the twentieth century. Various studies have been conducted to evaluate the compactibility of these mixtures when different methods of compaction are applied including refusal density, kneading, and impact compactors. The introduction of the Superpave Gyratory Compactor (Pine Instrument Company, Grove, Pennsylvania) (SGC) in the 1990s made it possible to monitor changes in specimen height during compaction and to better understand the process. Most of the methods for compaction study are based on the densification curve obtained from SGC compaction. This curve represents the change in the height of the specimen after each gyration, which can be later translated into a change in density or compaction (Leiva and West 2008; Mallick 1999).

Various methods have been proposed to evaluate the compactibility of asphalt mixtures. The Construction Densification Index (CDI) and the Transportation Densification Index (TDI) were introduced by Bahia et al. (1998). The CDI represents the effort required to compact an asphalt mix to 92%, whereas the TDI represents the energy required for vehicles to further compact from 92% to 98% during the service period. The CDI is the area under the densification curve limited by eight gyrations and compaction of 92%. The CDI can also be understood as the area under the densification curve with compaction in the range of 88%–92%. The TDI is defined as the area under the densification curve with compaction in the range of 92%–98%. In practice, the CDI represents the effort required to compact asphalt mix, while the TDI represents the compaction of asphalt mix by traffic to 98%.

The next method, the slope of densification curve, was presented by Anderson et al. (2002). The densification curve plotted logarithmically can describe the shear resistance of an aggregate's structure. Another method, utilized by Leiva and West (2008), is the number of gyrations to reach 92% compaction. It is widely accepted that an asphalt mix should be compacted in the field until it reaches a minimum compaction of 92%. It is expected that a mix is easy to compact up to 92%, allowing contractors to utilize less energy during construction. A mix becomes harder to compact above 92%, to better resist further compaction by traffic.

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An important concept found in the literature regarding compaction is the concept of the *locking point*. During compaction, aggregates are brought together, and a skeleton is developed made of coarse aggregates interlocked with each other. The point at which aggregates interlock is defined as the locking point. Initially, the locking point was proposed by William J. Pine, the engineer of the Illinois Department of Transportation (Transportation Research Board 2002). The locking point determines a point on the densification curve beyond which the mix skeleton starts to resist compaction. Different asphalt mixtures lock up at different numbers of gyrations. It is desirable for the locking point to be close to the final field compaction applied by the roller. Such asphalt mix permits easier field compaction by contractors and provides resistance to loads from traffic. Many ways of determining the locking point have been proposed. Mohammad and Shamsi (2007) report that the Alabama Department of Transportation describes the locking point as the point at which the sample being gyrated loses less than 0.1 mm between gyrations. The Georgia Department of Transportation describes the locking point as the number of gyrations at which the same height repeats three times. Vavrik and Carpenter (1998) introduced the most common practice, defining locking point as the first gyration in the first set of three gyrations at the same height, preceded by two sets of two gyrations at the same height.

Before the SGC was developed by the Strategic Highway Research Program in the early 1990s, there was little effort to understand compaction processes or the compactibility of asphalt mixtures. The lack of research effort can be attributed in part to the absence of equipment that is capable of providing sufficient data. The most widely used design methods in the pre-Superpave era were the Hveem and the Marshall methods. The Hveem method uses a kneading compactor, and the Marshall method uses an impact hammer to prepare samples. Neither of these provides sufficient data to evaluate compactibility (Roberts et al. 2002).

Recently, Polaczyk et al. (2018) described the compatibility of asphalt mixes when the impact (Marshall) method is applied. An accelerometer was placed on the falling mass of a Marshall Hammer (Humboldt, Elgin, Illinois), and acceleration was recorded after each blow. Data received from the accelerometer was filtered and analyzed. The accelerometer data showed the possible existence of a point similar to the locking point obtained from the Superpave Gyratory Compactor. This point was described as an impact locking point to distinguish it from the gyratory locking point. The impact locking point was described as the number of blows after which the response of the mix received by the accelerometer becomes stable, changing neither in peak acceleration nor duration of impact. Following the nomenclature from this research, in the present study the locking point obtained from the Superpave Gyratory Compactor is called the gyratory locking point to distinguish it from the impact locking point.

Objective and Scope

The objective of this research was to evaluate the locking characteristics of aggregate structure in asphalt mixtures through routine mixture design procedures. With this objective in mind, both the Marshall Compactor (Humboldt, Elgin, Illinois) and the Superpave Gyratory Compactor were used to evaluate the impact locking point and the gyratory locking point of different asphalt mixtures. Additionally, the samples for the gyratory locking point were compacted in two mold sizes to evaluate the effect of sample size on the compaction results. A total of ten mixtures was included in this study: seven dense-graded mixes with a maximum size of aggregate from 50.8 mm (2 in.) to 12.7 mm (1/2 in.) and three stone mastic asphalt (SMA) mixes with a maximum size of aggregate from 25.4 mm (1 in.) to 12.7 mm (1/2 in.). The maximum size of an aggregate is defined as the smallest sieve opening through which the entire amount of the aggregate is required to pass [AASHTO T2 (AASHTO 2007)]. The binder used was PG 64-22.

Laboratory Experiments

Materials

Ten hot mix asphalts were utilized in this study. First, different limestone aggregates were collected in eastern Tennessee, including #4, #5, #56, #7, and #10 stone screenings. The next step was to screen all the aggregates through the same set of sieves: 50.8 mm (2 in.), 38.1 mm (1.5 in.), 31.8 mm (1 ¼ in.), 25.4 mm (1 in.), 19.1 mm (¾ in.), 15.9 mm (5/8 in.), 12.7 mm (½ in.), 9.5 mm (3/8 in.), No. 4, No. 8, No. 30, No. 50, No. 100, and No. 200. The objective of the screening was to reduce aggregate variability and permit the design of a set of asphalt mixtures that possessed the same aggregate properties and would allow comparison of the locking points of different mixtures with limited influence of abrasion and angularity.

For all the mixtures, the same unmodified binder PG 64-22 was used to eliminate the influence of binder properties on the results. The mixing temperature for this binder was 154.4°C (310°F); the compaction temperature was 143.3°C (290°F).

Equipment

The compaction of specimens for the mix design was performed using a standard Marshall Mechanical Compactor (Humboldt, Elgin, Illinois)and the 101.6-mm (4-in.) molds. The same equipment was used to compact the specimens and thus determine the impact locking point. A data acquisition system was used to receive acceleration data and transmit it to the software. An accelerometer with a capacity of 49,050 m/s^2 (5,000g) was installed on the Marshall Hammer. For the Superpave specimens, the Superpave Gyratory Compactor was utilized to compact the material into 150-mm specimens and 100-mm specimens. The setup for the accelerometer and the Marshall Hammer is presented in Fig. 1.

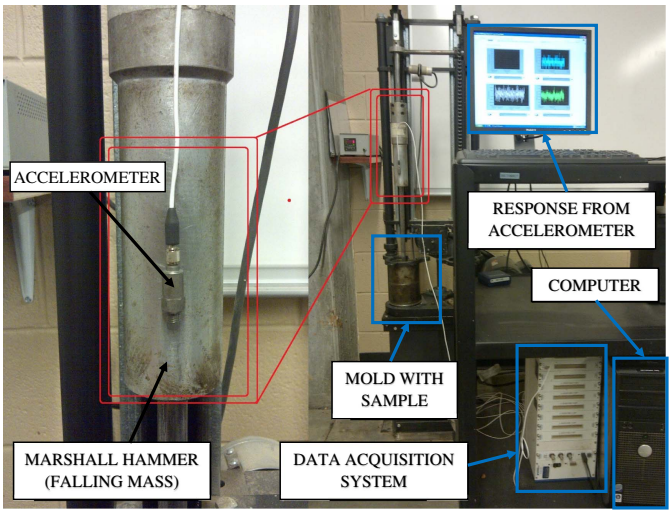

Fig. 1. Impact locking point experiment setup.

Table 1. Summary of hot mix asphalts granulometric composition

	Mix									
	1	2	3	4	5	6	7	8	9	10
Sieve	307A	307B	307BM2	307C	411D	411E	411TLD	SMA9.5	SMA12.5	SMA19.0
50.8 mm	100	100	—	—	—	—	—	—	—	—
38.1 mm	90	100	—	—	—	—	—	—	—	—
31.8 mm	—	—	100	—	—	—	—	—	—	—
25.4 mm	—	—	—	—	—	—	—	—	—	100
19.1 mm	60	77	87	100	—	—	—	—	100	95
15.9 mm	—	—	—	—	100	—	—	—	—	—
12.7 mm	—	—	—	—	97	100	100	100	93	57
9.5 mm	42	60	65	80	86	86	95	85	63	42
No. 4	30	42	48	52	65	65	65	39	24	24
No. 8	20	32	35	35	46	46	46	23	20	18
No. 30	12	16	19	18	23	23	25	—	—	—
No. 50	—	—	14	11	14	14	14	13	15	15
No. 100	5	7	8	6	7	10	7	—	—	—
No. 200	2.3	4.5	4.5	4.5	4.0	7.0	6.0	10.0	10.0	10.0

Note: All the values are in percentages.

Specimen Preparations

Once the material retained on each of indicated sieves was prescreened, the process of mix design started. For the seven dense-graded mixtures, the Tennessee Department of Transportation's specifications were used with modification for voids in the mineral aggregate greater than 14% (Tennessee Department of Transportation 2015). For the three stone mastic asphalt mixtures, the Georgia Department of Transportation's specifications were used (Georgia Department of Transportation 2013). The granulometric composition of each mixture was chosen as a middle point between the low and high limits provided in the specifications. A summary of the aggregates' composition is presented in Table 1. For each mixture, coarse and fine specific gravities were determined. The sieve No. 4 was used to sort the aggregates into coarse and fine groups. Next, four samples with different binder content were prepared for all ten mixtures. The specific gravity of each compacted specimen was tested, and the optimum binder content was determined. A summary of mix designs is presented in Table 2. The Marshall mix design was utilized to compact all the mixtures with a different number of blows depending on the mix type: dense-graded specimens received 75 blows for each side, and SMA specimens got 50 blows for each side. The same 101.6-mm (4-in.) mold size was used for all specimens. After the mix designs were completed, the production of asphalt mixes started, and around 25 kg of each mixture was prepared.

Table 2. Summary of hot mix asphalt designs

Number	Mix	Optimum AC (%)	Air void (%)	VMA (%)	VFA (%)	Blows
1	307A	3.5	4.0	14.0	71	75
2	307B	4.0	4.1	14.8	72	75
3	307BM2	4.4	4.0	15.2	74	75
4	307C	4.8	4.1	15.3	73	75
5	411D	5.5	4.0	15.6	74	75
6	411E	5.8	4.0	15.8	75	75
7	411TLD	5.8	4.0	15.7	75	75
8	SMA 9.5	6.8	3.6	18.2	80	50
9	SMA 12.5	6.4	3.5	17.9	80	50
10	SMA 19.0	5.9	3.5	17.2	79	50

Note: Optimum AC = optimum asphalt content; VFA = voids filled with asphalt; and VMA = voids in the mineral aggregate.

Test Procedure

The asphalt mixtures produced in the laboratory were placed in the oven for 2 h for short-time aging. Each mixture consisted of 11 specimens: five specimens for the impact locking point, three specimens for the gyratory locking point compacted in a 150-mm mold, and three specimens for the gyratory locking point compacted in a 100-mm mold. The weight of the samples for both the impact locking point and the gyratory locking point compacted in the 100-mm mold was 1,230 g, whereas the weight of samples for a 150-mm mold was 4,000 g. The accelerometer was placed on the falling mass of the Marshall Hammer and connected to the data acquisition system. The software was configurated to record the data with a frequency of 10,000 Hz. The Superpave Gyratory Compactor was set to compact the samples by applying 200 gyrations.

The samples used to test the impact locking point and the gyratory locking point compacted in the 150-mm mold were prepared for each mixture on the same day. Because it was time-consuming to change the Superpave compactor head from 150 to 100-mm, the samples for the gyratory locking point compacted in the 100-mm mold were prepared the next day. All the samples prepared for testing the impact locking point were compacted utilizing 75 blows on each side of the specimen (the samples for the SMA mix design had been compacted with 50 blows on each side). The compaction process was standardized at 75 blows on each side to maintain the same conditions for all the specimens and to allow comparison of the results. Similarly, the samples compacted via the Superpave Gyratory Compactor were all under the same condition of 200 gyrations.

Methods for Determining Locking Point

The impact locking point can be defined as the first blow of the impact hammer that produces stable peak acceleration and impact duration, which means the duration of the interaction between the hammer and the mixture. This method is based on the change of specimen stiffness during compaction. Initially, during the first blows applied to the specimen, the mixture is still loose, which implies low stiffness. During this initial stage of compaction, the peak

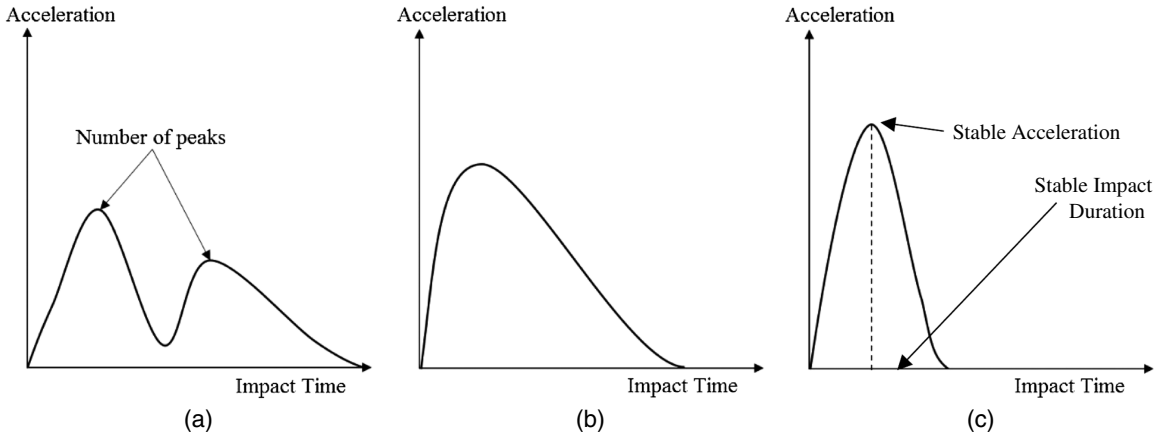

Fig. 2. Typical shapes of response plots in different compaction stages: (a) initial; (b) middle; and (c) at impact locking point.

acceleration is low, and the duration of impact is long. In this stage, various acceleration peaks can be observed, mostly limited to two peaks. As the compaction continues with every blow, the stiffness increases, peak acceleration increases, and impact duration decreases. After the impact locking point is reached, changes in stiffness become minimal, and peak acceleration and impact duration no longer see significant changes. A graphic presentation of the changes in acceleration and impact time is presented in Fig. 2.

Fig. 3 presents the acceleration data obtained from Mixture 4 (307C) Sample 1. The five graphs show the mixture response to compaction at 1, 10, 60, 129, and 150 blows. It can be observed that with every blow applied to the specimen the peak acceleration increased and the impact duration decreased until the locking point was reached at 129 blows. During the initial stage of compaction (Blow 1 and 10) there were two acceleration peaks. The acceleration increased from 2,305 m/s^2 (235g) at the first blow up to 4,807 m/s^2 (490g) at the locking point. The duration of impact decreased from 0.0035 s (Blow 1) to 0.0013 s (Blow 129, i.e., locking point). After that, the peak acceleration varied between 4,699 m/s^2 (479g) and 4,817 m/s^2 (491g), and impact duration between 0.0013 and 0.0014 s.

The impact locking point can be used to indicate a boundary that separates effortless and effortful compaction. Difficult compaction means that there is no meaningful change in density and further compaction can lead to aggregate damage. Polaczyk et al. (2018) measured change in density to confirm that after crossing the locking point, the change in density is significantly smaller than before the mixture reaches the locking point. Three samples were compacted, first at 150 blows, second at the impact locking point, and third at 15 blows below the impact locking point. On average, samples that were compacted at 15 blows below locking point had air voids 1.2% higher than at the final compaction, while samples that were compacted at the locking point had air voids only 0.19% higher than at the final compaction.

The gyratory locking point was determined by following the Georgia Department of Transportation (GDOT) method, which defines the locking point as the number of gyrations at which the same height repeats three times. Initially, the method developed by Vavrik and Carpenter (1998), who introduced commonly used definition that defines the locking point as the first gyration in the first set of three gyrations at the same height that is preceded by two sets of two gyrations at the same height, was utilized in this study. However, it was impossible to obtain the correct result for several specimens because the sequence 2-2-3 does not necessarily appear in all densification curves.

Results and Data Analysis

Impact Locking Point

In this study, a variety of mixtures were utilized: ten mixtures that included three SMA and seven dense graded. An important improvement over previous research was the consideration of the variability of aggregates by screening and producing unvarying material for each of the sieves. The materials were screened by sieves to minimize variation of aggregates for each mixture, thereby eliminating aggregate variability as a factor in the results. Fig. 4 presents the results of the impact locking point.

The number of samples for each mixture was fixed at five because of the availability of material. The final value of the impact locking point was calculated as the average of the five samples. It was not possible to determine the impact locking point for Mixture 1 (307A) or for Samples 3 and 4 of the Mixture 2 (307B), suggesting that the locking point for these mixtures may be higher than 150 blows. However, in the case of Mixtures 1 and 2, the failure to reach a locking point may be attributable to the breakage of aggregates, especially the largest coarse aggregates. The specimens of Mixtures 1 (307A) and 2 (307B) are depicted in Fig. 5.

The breakage of aggregates, caused by the impact hammer, made it impossible for the aggregates to lock down and yield steady readings of the peak acceleration and impact duration. Once compaction of the specimens was terminated, the samples were warmed and separated sounds with the objective to review the magnitude of damage caused by the impact hammer. To determine breakage, all sides of the aggregates that were not covered with asphalt cement were examined. Postcompaction gradation (sieve analysis) was also performed on aggregate previously washed with the solvent. The comparison of pre- and postcompaction sieve analysis is presented in Fig. 6. The conclusion of the review was that some of the larger particles suffered a rupture. This phenomenon was particularly visible in Mixture 1, which suffered the most extensive damage. The 4-in. mold may be inadequate to perform this experiment on mixtures with particles larger than 25.4 mm (1 in.). Also, the limestone aggregates may be too soft to prevent particle damage before compaction is terminated.

The value of the locking point for Mixture 1 has not been concluded. However, for Mixture 2, three out of five samples gave valid results, and the final value was calculated as the average of the three samples. Sample 4 of Mixture 4 (307C) was discarded due to human error during the compaction process. For the rest of the mixtures, it was possible to obtain five different samples and calculate averages.

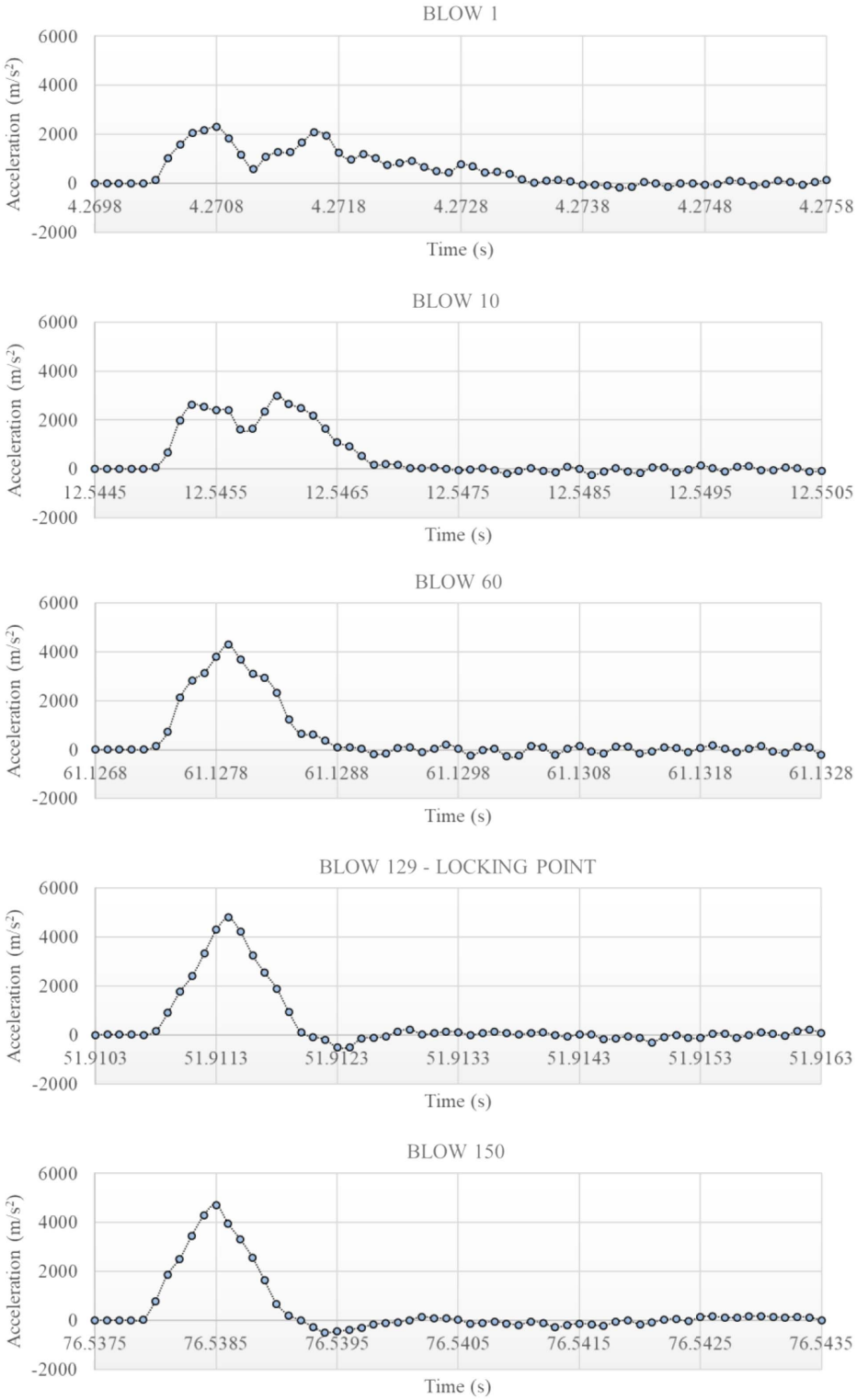

Fig. 3. Example of the acceleration data and determination of the locking point.

The results show that for dense-graded asphalt mixtures, the impact locking point decreases with decreasing maximum aggregate size and ranges from 145 blows for Mixture 2 to 96 blows for Mixture 7. Also, it can be concluded that base course asphalt mixtures have higher impact locking points, with an average of 138 blows, whereas surface asphalt mixtures have lower impact locking points, with an average of 103 blows. The stone mastic asphalt (SMA) mixtures follow the pattern that the impact locking point increases with increasing size of aggregates utilized in the mixture. However, the range of the impact locking point is significantly smaller, from 102 blows for the 9.5-mm mixture to 105 for the 19.0-mm mixture.

The average result of the impact locking point for the base course indicates that it is close to the 150 blows that are commonly used for the Marshall Mix Design of dense-graded mixtures. The difference between the locking point and the final compaction is 12 blows, which means the samples for the mix design are slightly overcompacted. The result obtained for the surface asphalt mixture,

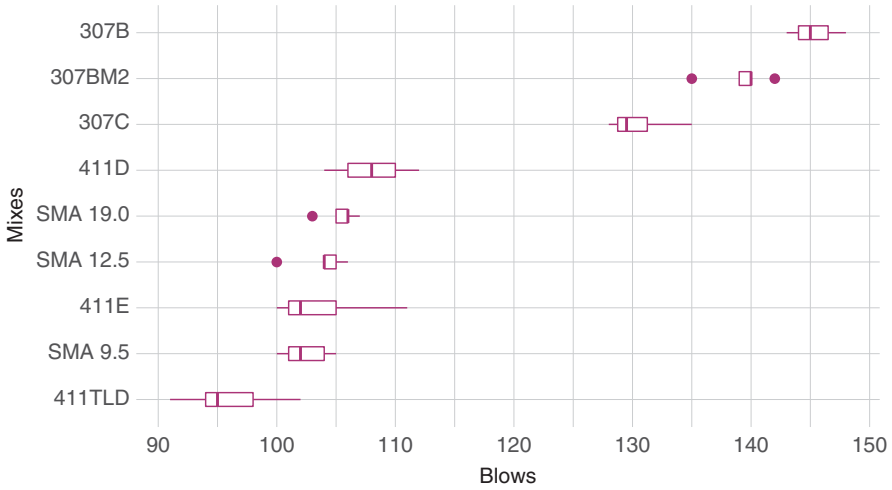

Fig. 4. Summary of the impact locking points.

Fig. 5. Example of aggregate damage: (a) Mixture 1 (307A); and (b) Mixture 2 (307B).

103 blows, indicates that there is a difference of 47 blows between the impact locking point and final compaction. This can lead to significant overcompaction, in extreme cases even damage to aggregates and errors in the mix design. From the results in Fig. 3, it can be concluded that the average stone mastic asphalt specimen, when compacted at 50 blows for each side, misses only 4 blows to reach the impact locking point. The results also show that average dense-graded asphalt mixture requires higher compaction energy to achieve the impact locking point than the SMA mixture requires.

Gyratory Locking Point

Fig. 7 presents data from the 150-mm mold. Similarly to the results obtained from impact hammer, the gyratory locking point for the dense-graded asphalt mixtures increases as the maximum aggregate size increases. Again, the base mixtures obtained a higher average gyratory locking point of 80 gyrations than the surface mixtures, which achieved an average gyratory locking point of 47 gyrations. The stone mastic asphalt mixtures had an average gyratory locking point of 94. It can be shown from the gyratory locking points results that when the mixture has coarser aggregates the gyratory locking point is higher. The difference between the locking points for SMA mixture is not as pronounced as for the dense-graded mixtures, for which the difference is around one gyration for two blows. The interesting finding is that the gyratory locking point of the SMA is much higher than that of the dense-graded mixture. Also, for the SMA, the compaction effort required to achieve both locking points is similar, 94 gyrations for the gyratory locking point or 103 blows for the impact locking point.

Fig. 8 presents the gyratory locking points obtained from the 100-mm diameter mold. The objective of utilizing different mold sizes was to analyze how mold size influences the locking points results. Previous research efforts focused on investigating whether differences in mold size affect compaction and properties of the asphalt mixture. Hall et al. (1996) investigated how the size of the sample affects compaction and volumetric properties of asphalt mixtures. The study utilized the same 150-mm mold for all the samples, and the weight of the samples varied from 2,000 to

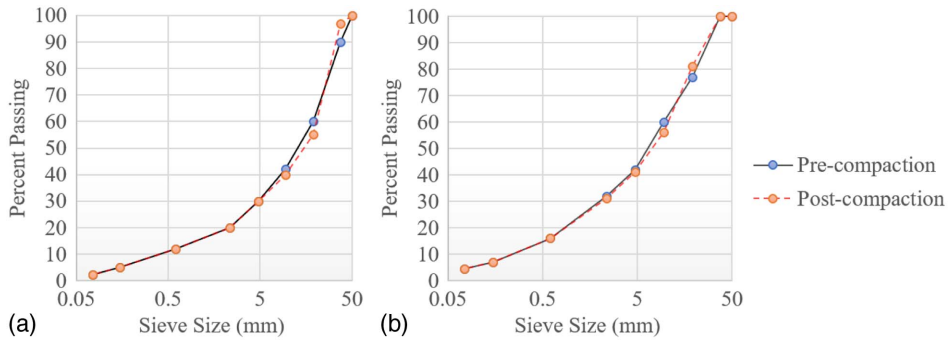

Fig. 6. Pre- and postcompaction sieve analysis: (a) Mixture 1 (307A) Sample 1; and (b) Mixture 2 (307B) Sample 3.

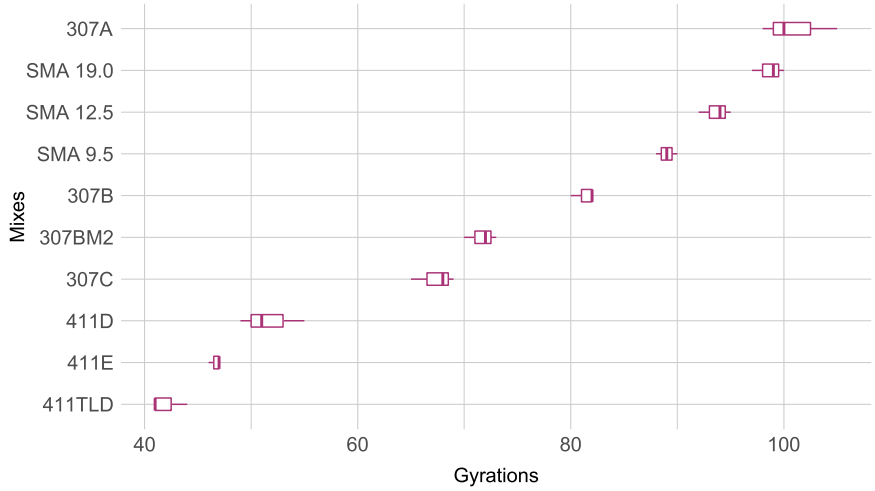

Fig. 7. Summary of the gyratory locking points (150-mm mold).

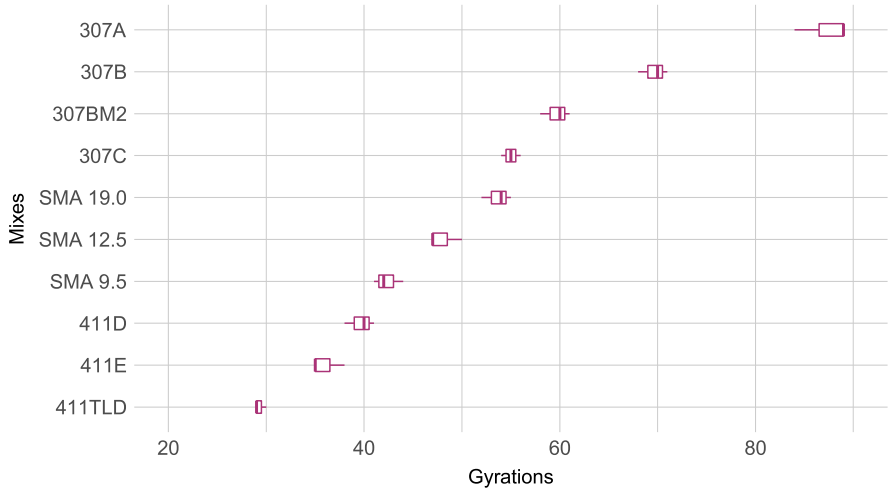

Fig. 8. Summary of the gyratory locking points (100-mm mold).

6,500 g. Hall and colleagues concluded that compaction characteristics and volumetric properties change with the size of the sample. McGennis et al. (1996) presented the hypothesis that for the same mixture and the same number of gyrations, the resulting compaction should be the same for both molds. Two 12.7-mm (½-in.) and five 19.1-mm (¾-in.) nominal maximum size aggregate mixtures were tested. Specimens were prepared at the optimum asphalt content in the 150-mm and the 100-mm gyratory molds. Specific gravities of specimens from the two mold sizes were compared. More than half of the results rejected this hypothesis. Jackson and Czor (2003) evaluated the use of the 100-mm mold to prepare test samples in the laboratory by collecting different mixes and comparing relative density obtained with the 100-mm mold and the 150-mm mold. This work found significant statistical differences between the results obtained from two sizes of molds. Nonetheless, the recorded differences were smaller than could be measured given the precision of the laboratory test methods, and the researchers concluded that there is no significant difference from an engineering point of view.

In the current study, the specimens compacted in 100-mm mold had the same aggregate and binder properties as samples compacted with the Marshall Hammer and 150-mm SGC molds. As Fig. 8 shows, the gyratory locking point for the 150-mm specimens was significantly higher than that of the 100-mm specimens, which means more compaction efforts will be required to achieve skeleton structure in asphalt mixture if larger molds are used for specimen compaction. However, even with this significant difference in values of gyratory locking points, the results indicated that the rankings of mixtures for the two different mold sizes were identical. These rankings support the conclusion that the concept of locking point can discriminate the compaction properties of one mixture from another no matter which mold size is used.

Fig. 9 presents a summary of all the locking points obtained during this research. It can be observed that the gyrations are more efficient in achieving the locking point than impact regardless of the mold used. However, the difference is higher for dense-graded mixtures. For all the mixtures, the ranking of locking points was maintained, but again for dense-graded mixtures, the difference was more significant than for SMA. The small difference in locking points for SMA may be attributed to the granulometric composition of these mixtures, for which the finer sieves do not vary. These results may indicate that the finer particles of granulometric composition have a more significant influence on the locking point than courser aggregates.

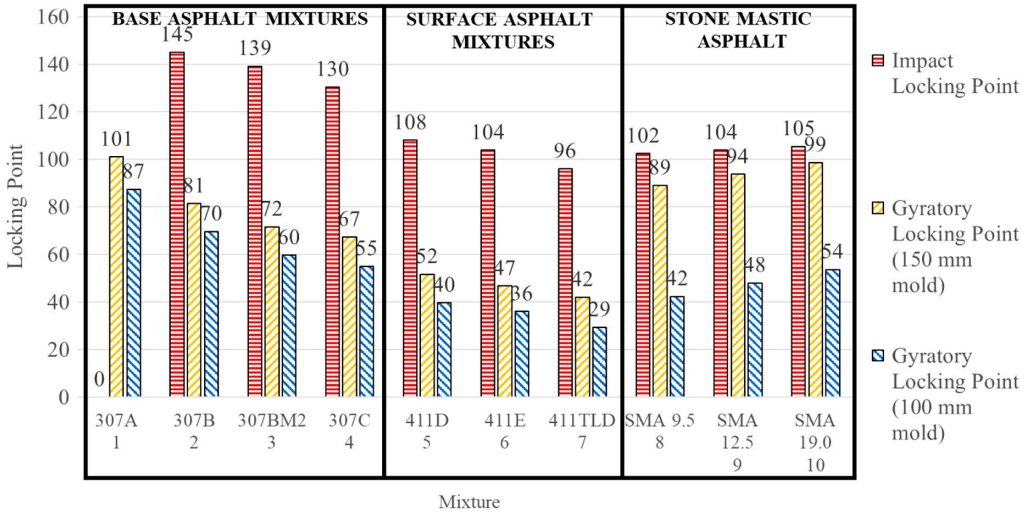

Fig. 9. Summary of the locking points.

Summary and Conclusions

In this study, two compaction methods, the SGC and Marshall Compactor, were used to investigate the locking points of asphalt mixtures. Ten different asphalt mixtures were produced with the same aggregates prescreened with sieves to eliminate the influence of aggregate gradation. The specimens were compacted utilizing a Marshall Hammer with an accelerometer attached to the falling mass and then with the SGC. The response of specimens obtained by the accelerometer and the change in specimen height in the SGC compaction were measured to determine impact and gyratory locking points for each mixture. The following conclusions were drawn based on the results of this study:

- The impact locking point can be determined with an accelerometer attached to the Marshall Hammer. For researchers, it can be used to evaluate the compactibility of an asphalt mixture. For contractors, it can provide an easy way to determine the effort required to compact an asphalt mixture in the field.
- The locking point is related to the full gradation of the blend consisting of coarse and fine aggregates. Dense-graded mixtures show a wider range in locking points than SMA mixtures. This difference may be attributed to granulometric variation. Dense-graded mixtures vary in both coarse and fine aggregates, whereas SMA mixtures vary mostly in coarse aggregate. In this study, the range of optimum asphalt content for dense-graded mixtures was 2.3%, whereas for SMA, the range is 0.9%. Thus, variation in asphalt content can affect the locking point.
- In this study, dense-graded mixtures with smaller maximum aggregate size had lower locking points. This finding may be attributed to the fact that these mixtures generally contain more asphalt binder, which serves as a lubricant and makes compaction easier and faster. In this study one type of asphalt binder was used. Further research is needed to determine the influence of the asphalt binder on the locking point, especially the difference between modified and unmodified binder.
- The locking point of base mixtures was slightly under 150 blows, the common number of blows in the Marshall Mix Design. The SMA had the impact locking point just above 100 blows, again the common number in the mix design. In contrast, surface mixtures showed an impact locking point far below 150 blows. This finding indicates that surface mixtures may suffer overcompaction and aggregate breakage when 150 blows are used for mix design. To address this problem, further study is needed, which would include performance comparison between mixtures compacted traditionally and at the locking point.
- The samples that contained particles larger than 25.4 mm (1 in.) were damaged during compaction. The 101.6-mm (4-in.) Marshall mold may not be adequately large for determining the impact locking point for mixtures with the aggregate particles larger than 25.4 mm (1 in.).
- The gyratory locking points for the 150-mm specimens were significantly higher than those for 100-mm specimens, but the ranking is maintained regardless mold size. This finding allows the comparison of the locking points for different mixtures if the same size of mold is utilized. In the current study, all comparisons were made with the samples of the same weight. Further study is needed to determine if the weight (height) of specimen will have influence on the locking point.
- The scope of this research was limited to evaluate the locking point of various types of asphalt mixtures. Further work is needed to correlate the locking point with performance tests and mix design parameters.

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